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High Power Dynamic Polarization Control Using Plasma Photonics

D. Turnbull

February 19, 2016

NIIF and JLF User Group Meeting
Livermore, CA, United States
January 31, 2016 through February 3, 2016

Disclaimer

High Power Dynamic Polarization Control Using Plasma Photonics

NIF and JLF User Group Meeting

David Turnbull
Experimental Physicist, National Ignition Facility, LLNL

2 February 2016

LLNL-PRES-XXXXXX
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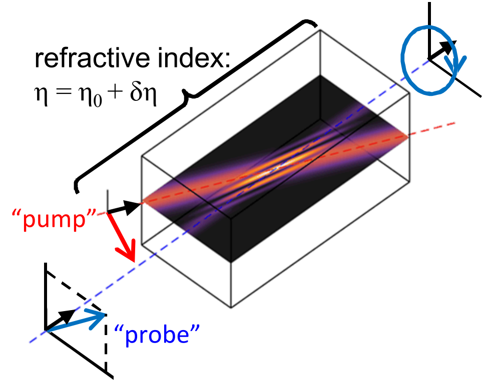
Plasma photonics is the manipulation of light using plasma, at fluences beyond the damage threshold of conventional optics

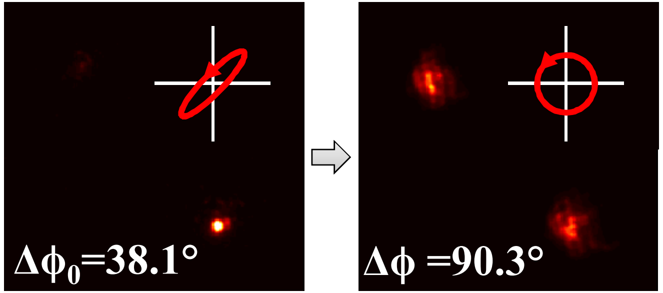
THEORY

- We recently proposed[1] that a [pump + plasma] optical system can alter the polarization of a crossing probe beam
  - Introduced "plasma photonics" concepts (laser-plasma waveplates/polarizers)

JLF

- An ultrafast high-power tunable plasma waveplate has been demonstrated at JLF[2]
- Wavelength tuning (new capability!) will enable the plasma polarizer & other expts on 4-wave mixing and crossed-beam energy transfer





[2]D. Turnbull *et al, in preparation* (2016)
[1]P. Michel, L. Divol, D. Turnbull, & J. D. Moody, *Phys. Rev. Lett.* **102**, 205001 (2014)

Acknowledgments

- S. Ayers[1], P. Bell[1], T. Chapman[1], C. Chen[3], R. Chow[1], L. Divol[1], C. Goyon[1], G. Frieders[1], R. L. Hibbard[1], P. Michel[1], J. D. Moody[1], B. B. Pollock[1], J. E. Ralph[1], J. S. Ross[1], J. R. Stanley[1], E. Tubman[2], J. L. Vickers[1], N. Woolsey[2], Z. M. Zeid[1]

[1]*National Ignition Facility, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[2]*York Plasma Institute, University of York, Heslington, York Y010 5DQ, United Kingdom*
[3]*Department of Electrical Engineering, Cornell University, Ithaca, NY 14850, USA*

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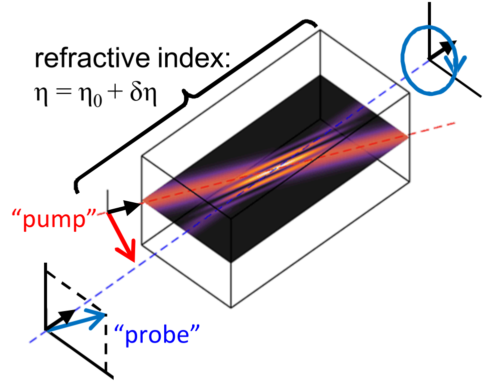

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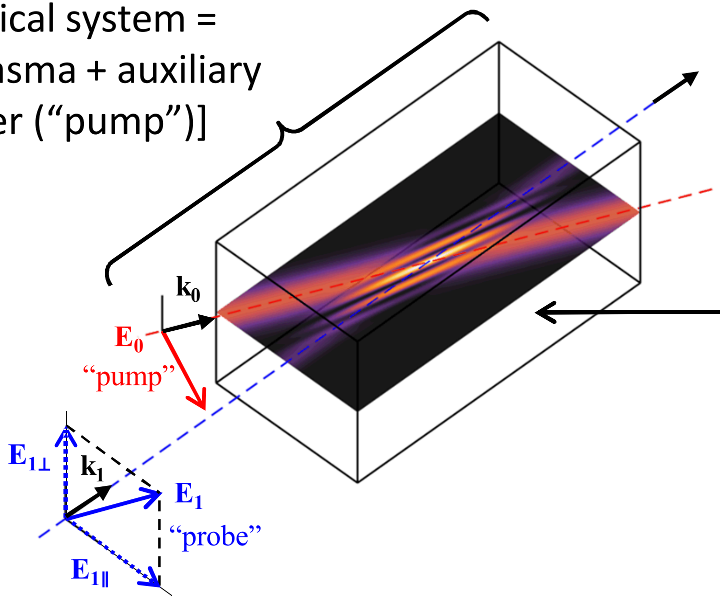
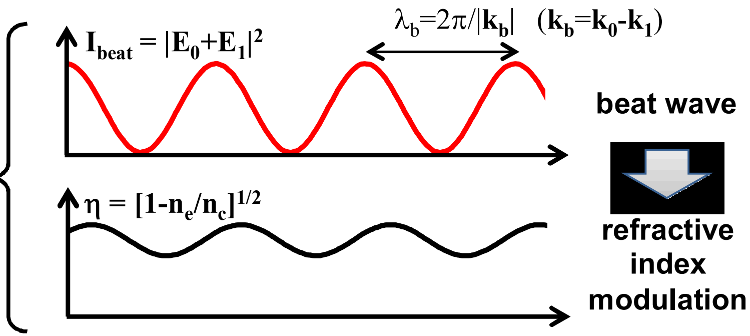
Fundamental properties of light waves can be modified by optical wave-mixing in plasmas

optical system = [plasma + auxiliary laser (“pump”)]



probe modified by scattering off the refractive index modulation imprinted by the beat wave:



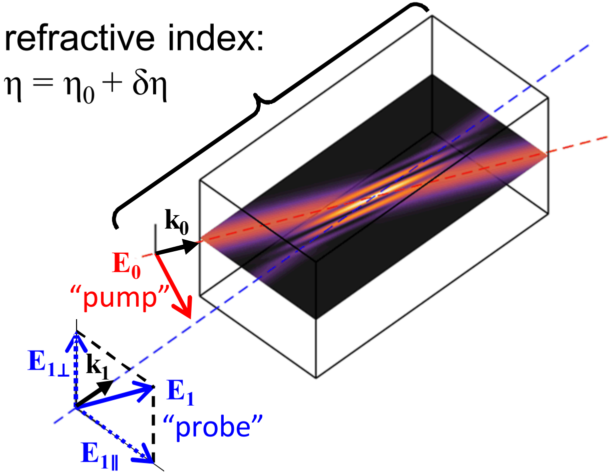
By using wave-mixing, plasmas can be turned into “photonic devices” that can sustain extreme laser fluences (>10^6× traditional optics)

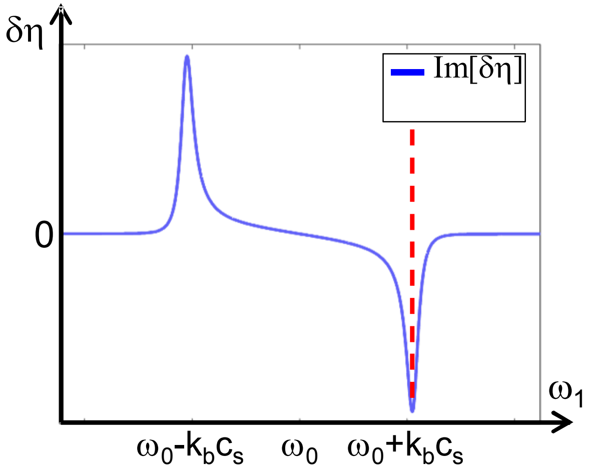
The refractive index modulation can alter both the amplitude and phase of the probe beam

The refractive index perturbation $\delta\eta$ is complex:

- $\mathrm{Im}[\delta\eta]$: exponential growth/decay vs. z (energy transfer with the pump)

refractive index:
$\eta = \eta_0 + \delta\eta$





$\omega_1 = \omega_0 \pm k_b c_s$: beat wave resonantly drives an ion-acoustic wave (IAW)

Alters the probe beam amplitude (foundation of CBET on the NIF)

The refractive index modulation can alter both the amplitude and phase of the probe beam

The refractive index perturbation $\delta\eta$ is complex:

- $\mathrm{Im}[\delta\eta]$: exponential growth/decay vs. z (energy transfer with the pump)
- $\mathrm{Re}[\delta\eta]$: change in average refractive index seen by the probe, $\eta_0 \rightarrow \eta_0 + \mathrm{Re}[\delta\eta]$

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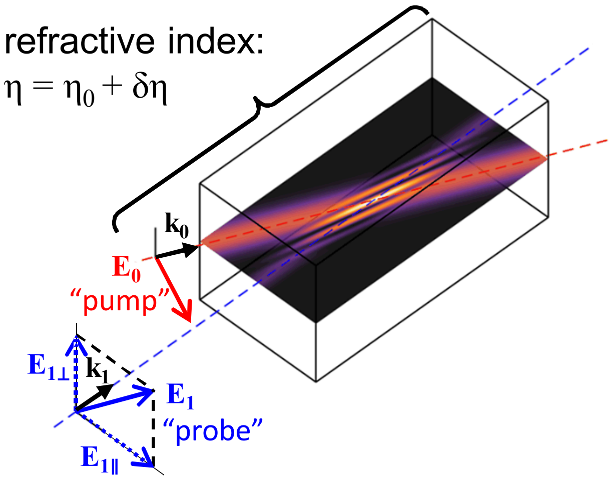
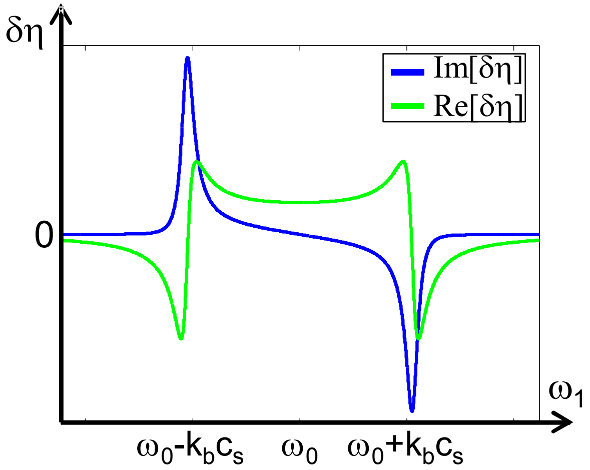


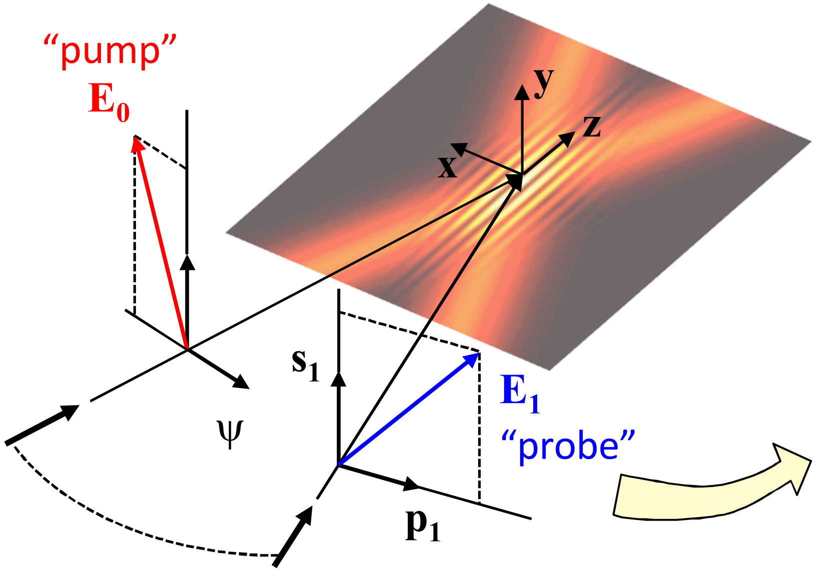


$\mathrm{Im}[\delta\eta] \leftrightarrow \mathrm{Re}[\delta\eta]$
(Kramers-Kronig)

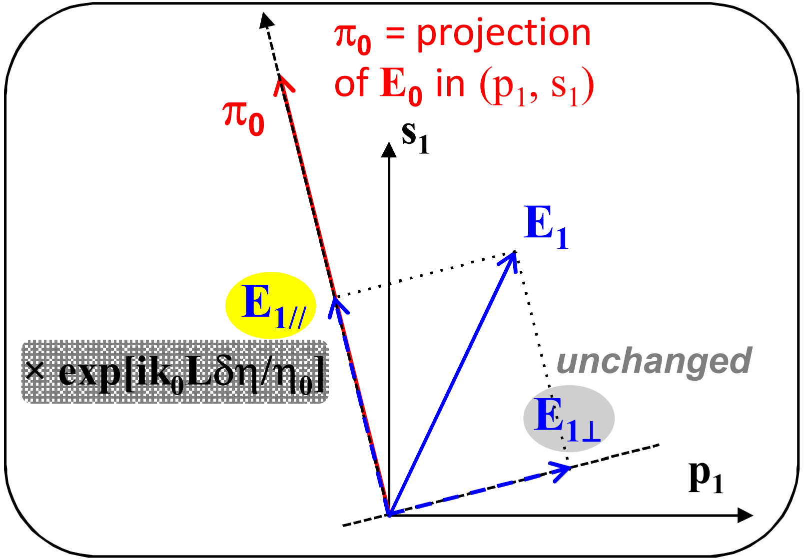
Alters the probe beam phase

The refractive index perturbation $\delta\eta$ is only experienced by the probe's E-field component parallel to the pump's E-field

Geometry for arbitrary polarizations:

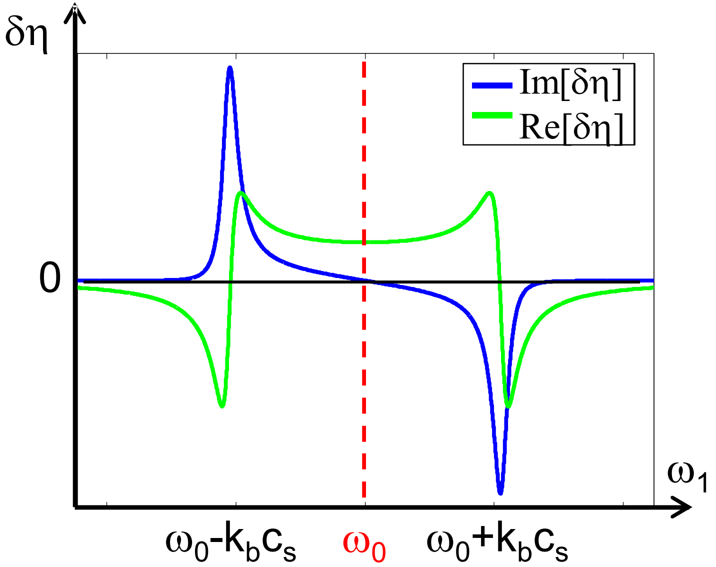


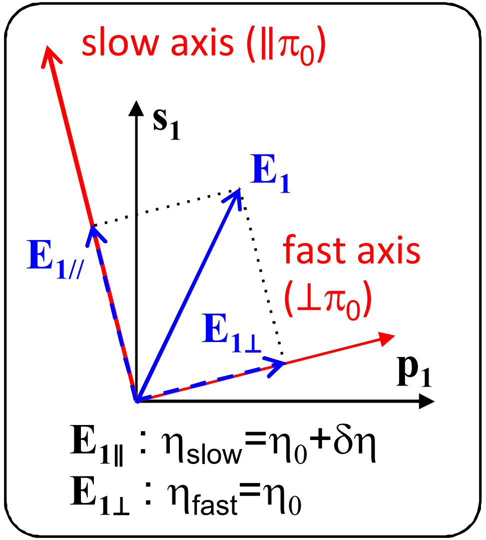
Probe's plane of polarization:



The [pump + plasma] optical system is optically anisotropic

An interesting limiting case involves pure birefringence without any energy transfer





The phase delay $\delta\eta \propto \mathbf{L I_{pump} n_e / T_e}$ can be easily tuned by varying these parameters

P. Michel, L. Divol, D. Turnbull, & J. D. Moody, *Phys. Rev. Lett.* **102**, 205001 (2014)

The implication is that a [pump+plasma] system can be used as a tunable waveplate

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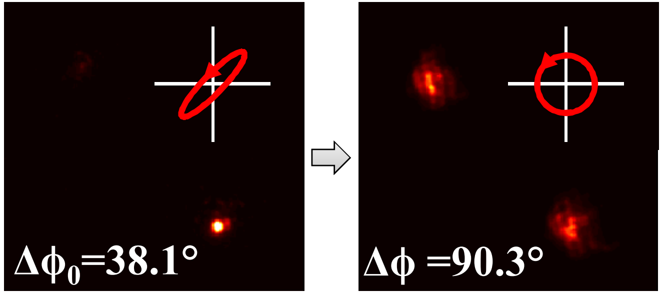

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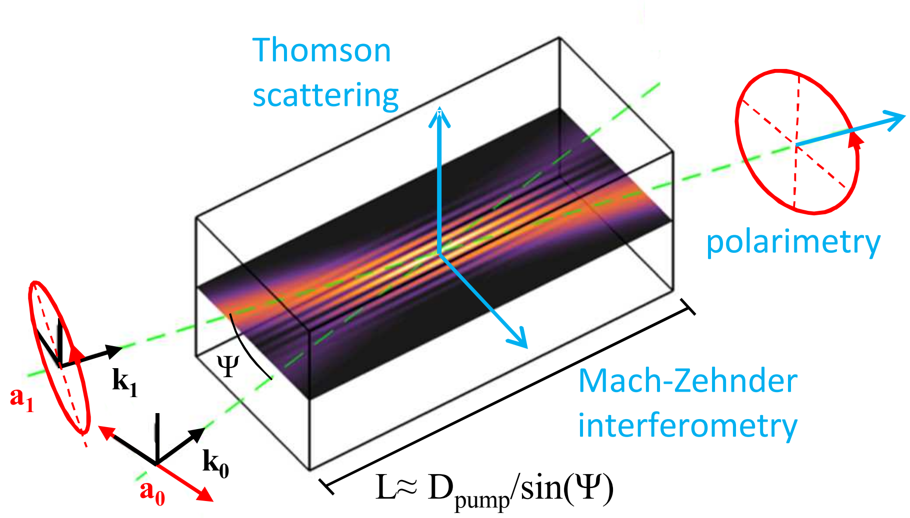
A JLF campaign was conducted to validate the theory and demonstrate a laser-plasma waveplate



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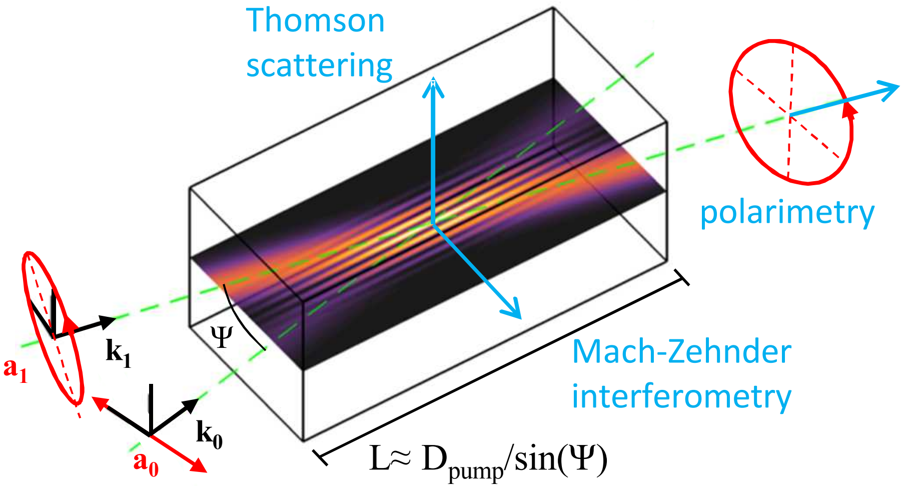

$\lambda_0 = \lambda_1 = 1.053\mu m$
$D_0 = 600\mu m$
$L \approx 1.2 mm$

$I_0 \approx 2 - 10\ [10^{13}\ W/cm^2]$
$n_e/n_c \approx .7 - 3.3\%$
$T_e \approx 180 - 380 eV$

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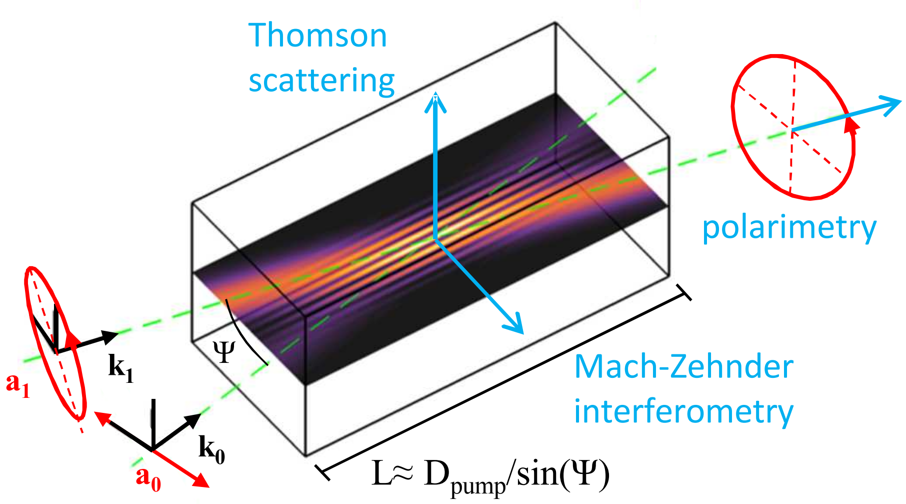

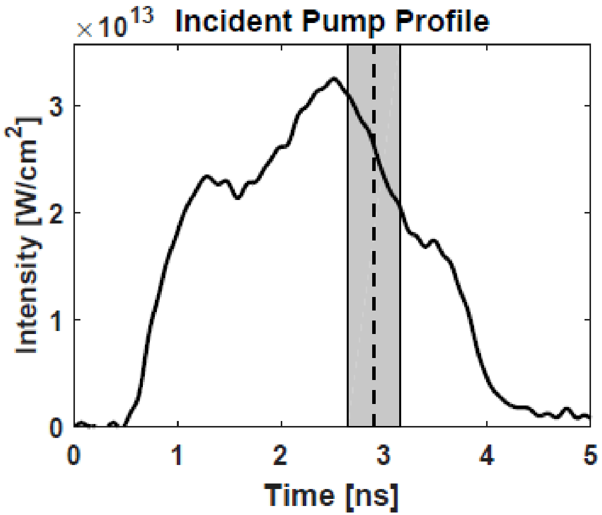

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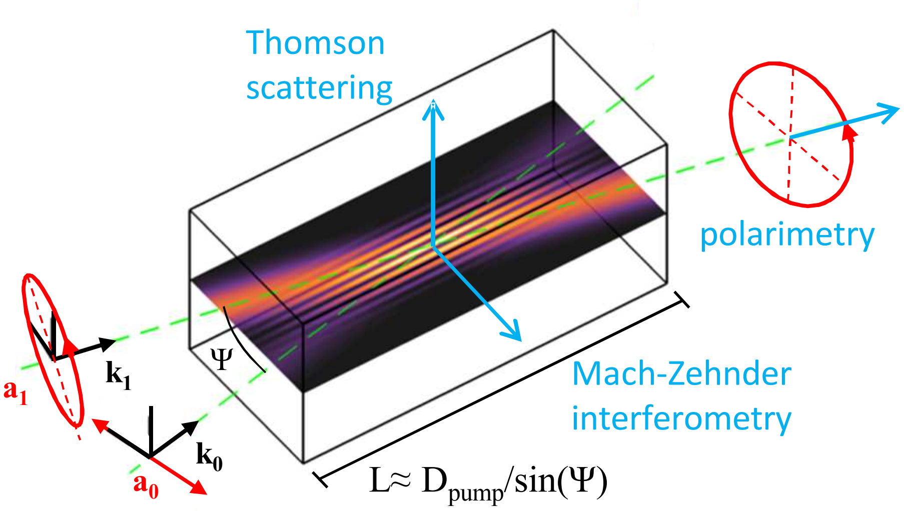

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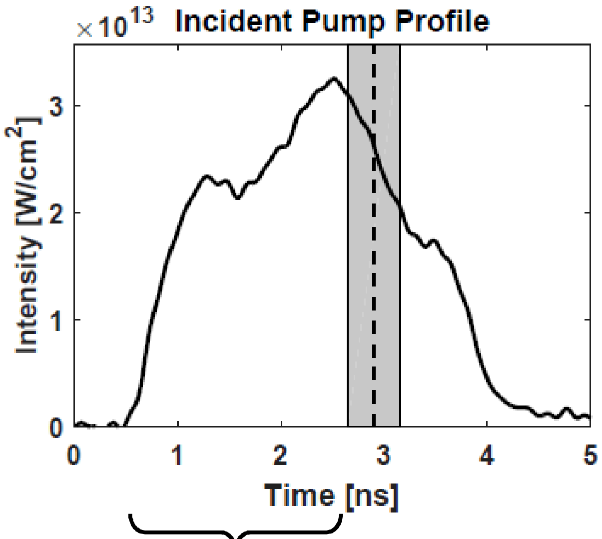
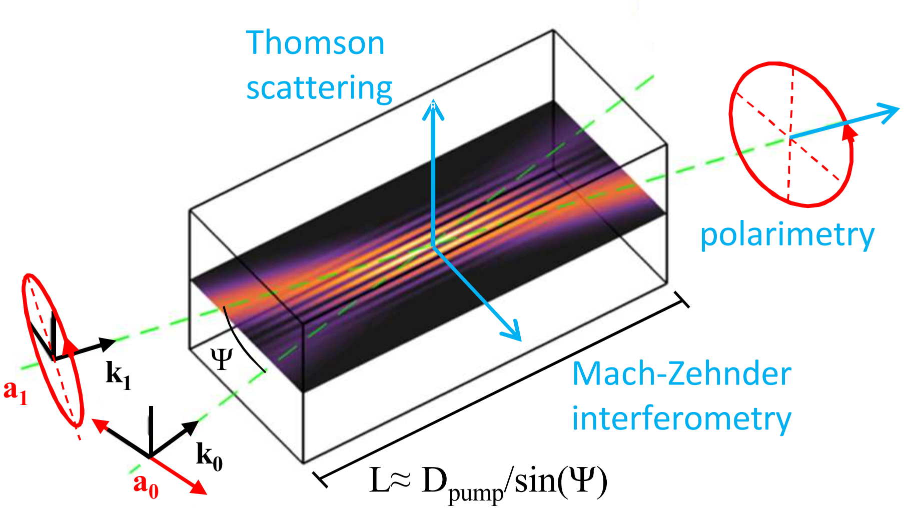


Ionizes gas and sets plasma conditions

A JLF campaign was conducted to validate the theory and demonstrate a laser-plasma waveplate



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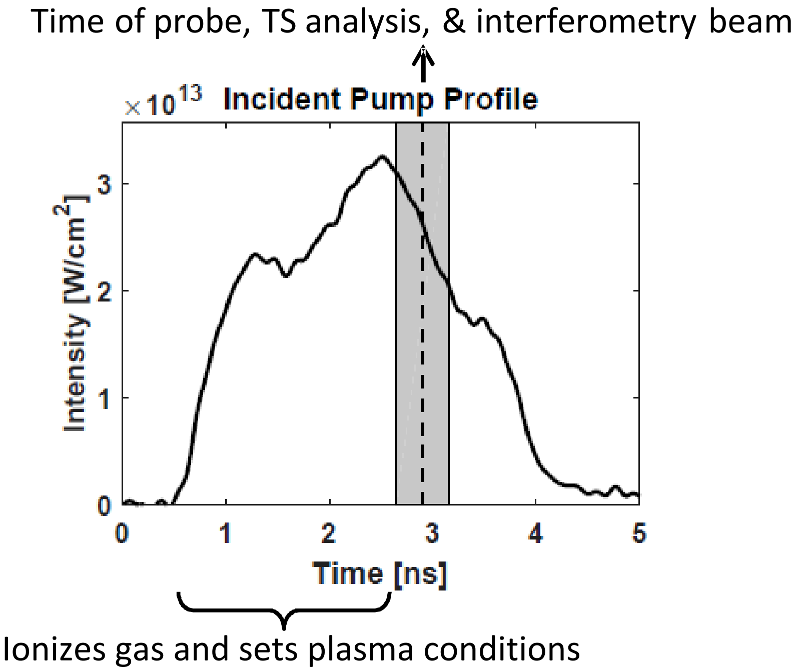

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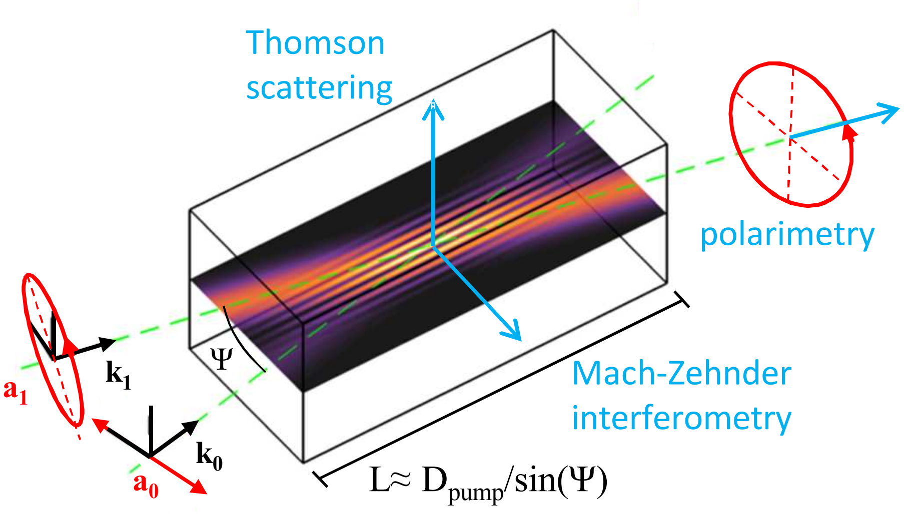

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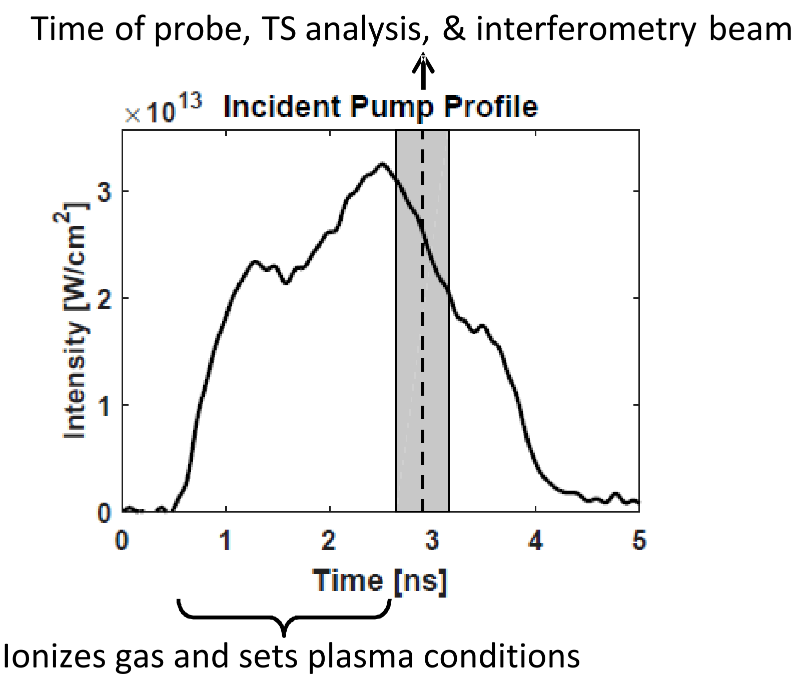
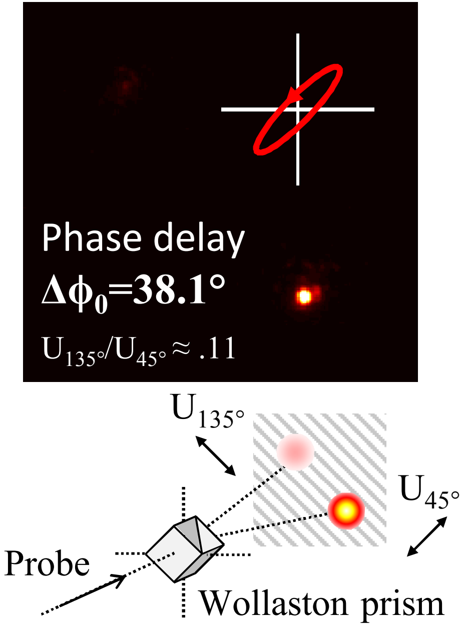


The crucial parameters – I_0, n_e, T_e, interaction length L– were carefully controlled/measured

Elliptical probe was converted to a nearly ideal circularly polarized beam by inducing a 52° phase delay in plasma



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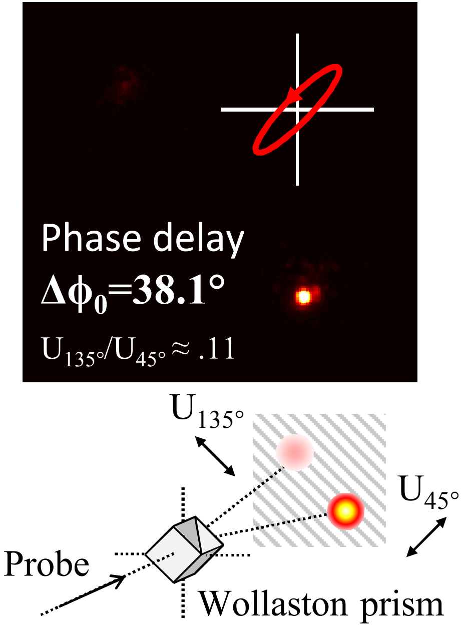

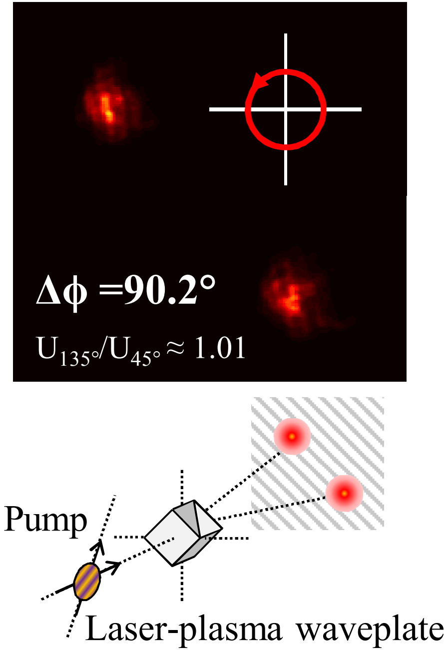

JLF

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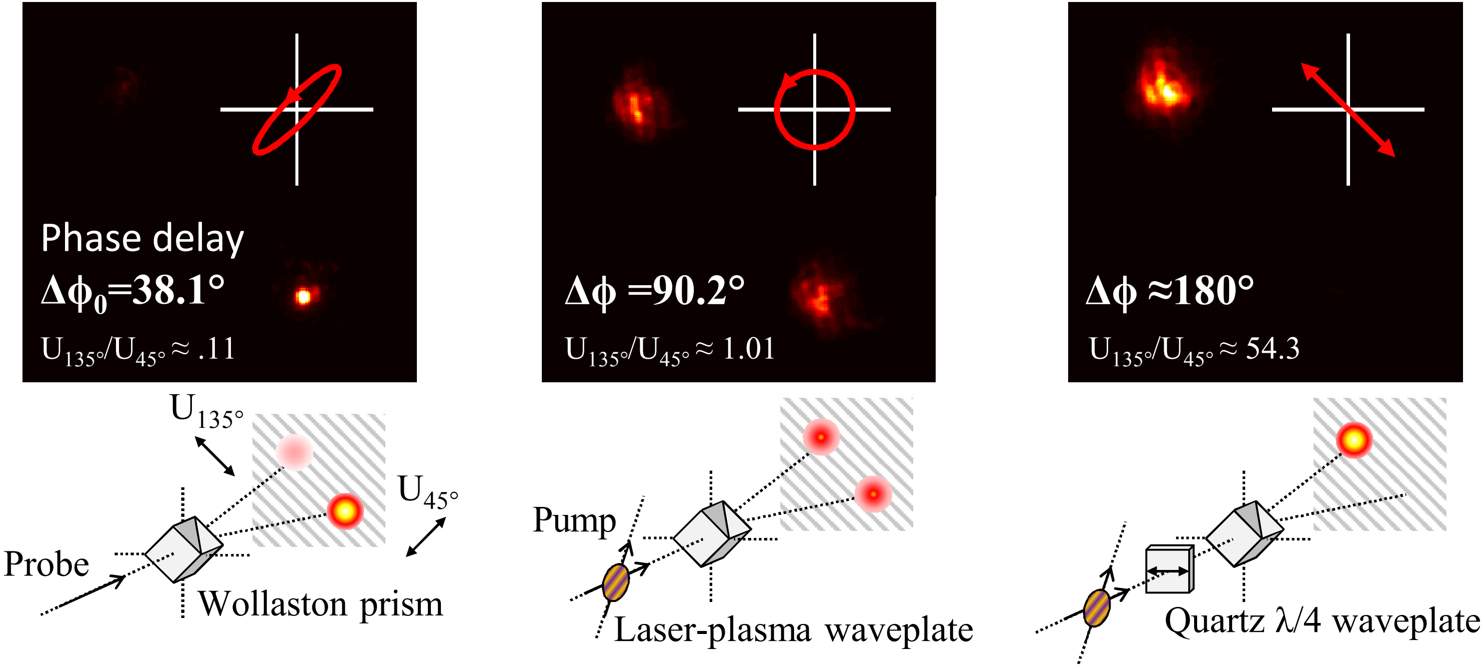

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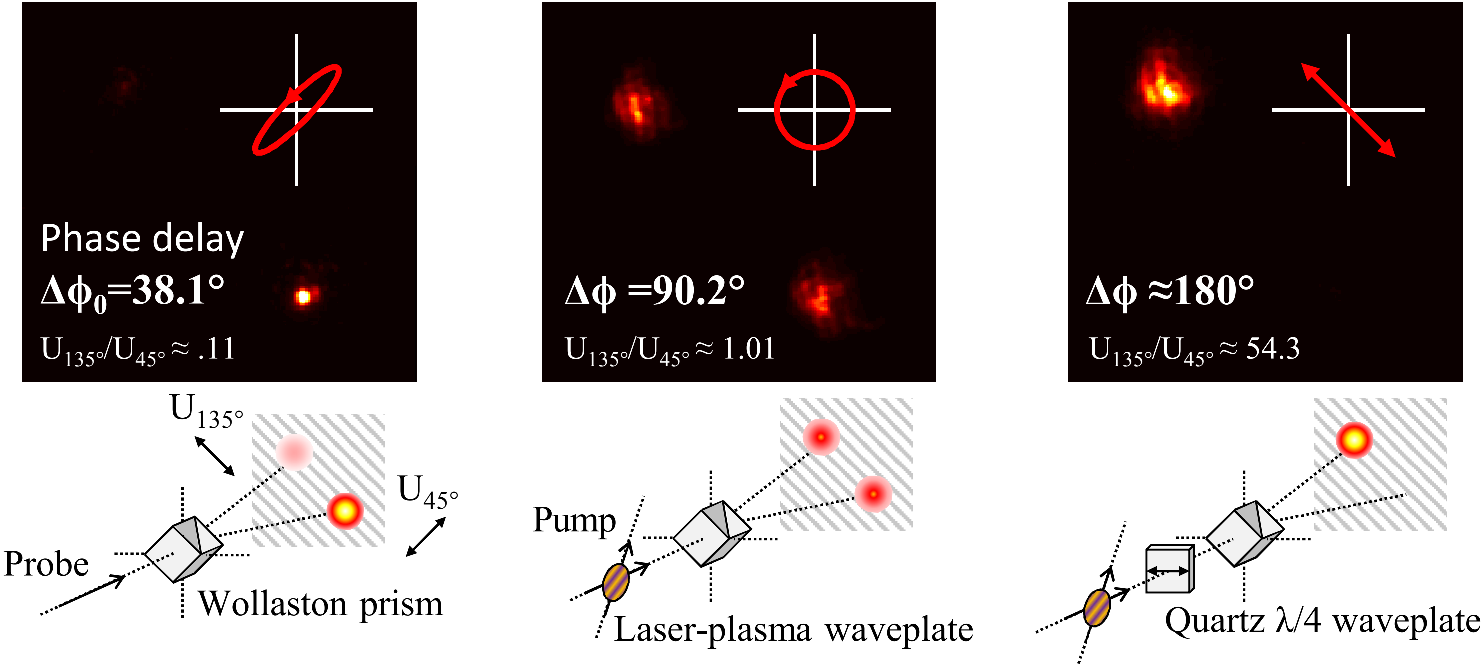
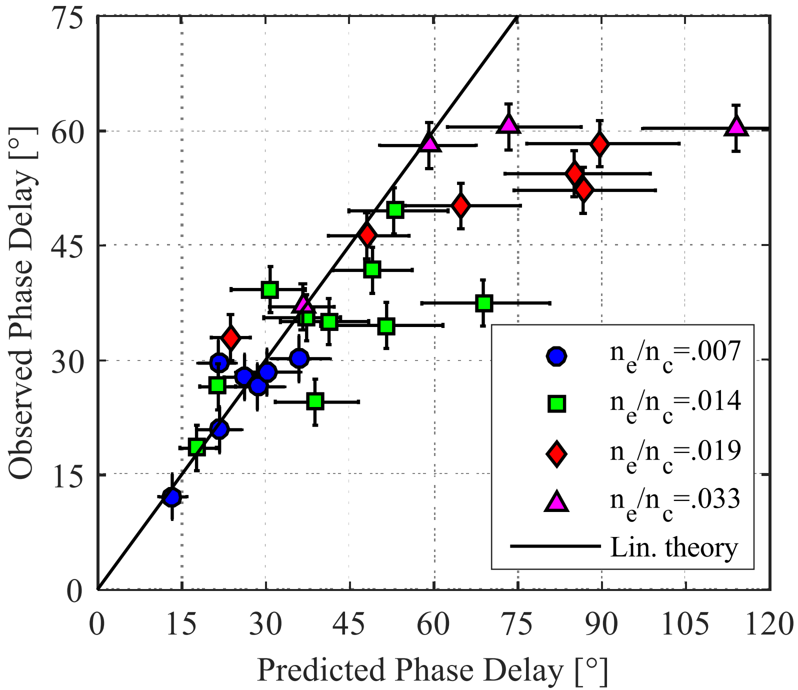
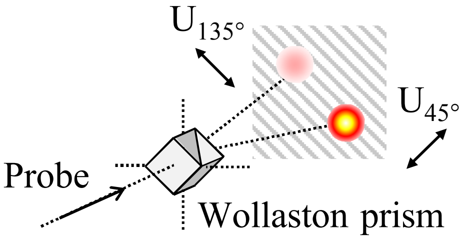


This is the first demonstration of a near-ideal tunable laser-plasma waveplate

Data in excellent agreement with linear theory at moderate intensity and density





Observed:

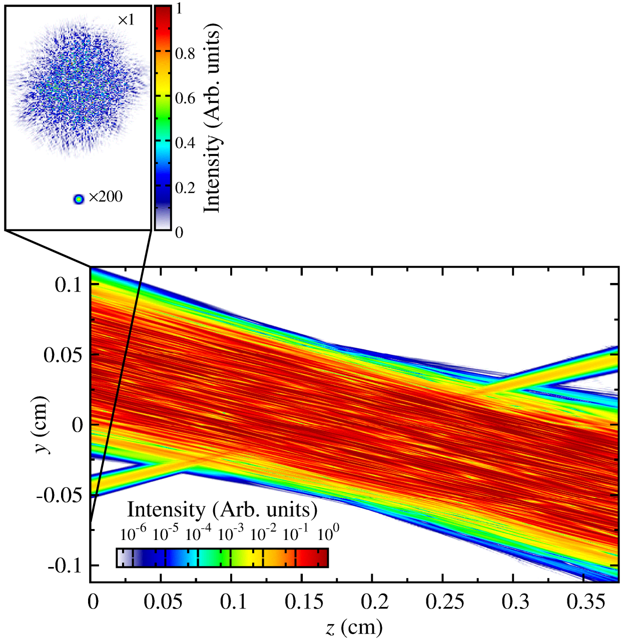
$$\Delta\phi = 2tan^{-1}(\sqrt{U_{135°}/U_{45°}})$$

Predicted:

$$\Delta\phi = 1.68 \times 10^{-11}\lambda_0[\mu m]L[mm]\frac{n_e/n_c}{T_e[keV]}\left(I_p\cos(\psi) + I_s\right)$$

Results validate the theory in [Michel *et al*, PRL, 2014] in the weak-coupling regime of SBS

pF3D simulations capture the trends observed in the data



Simulations by T. Chapman

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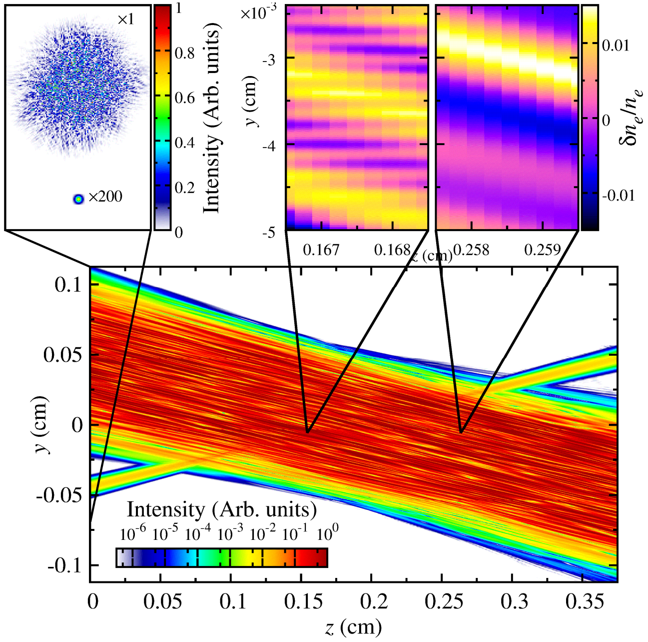

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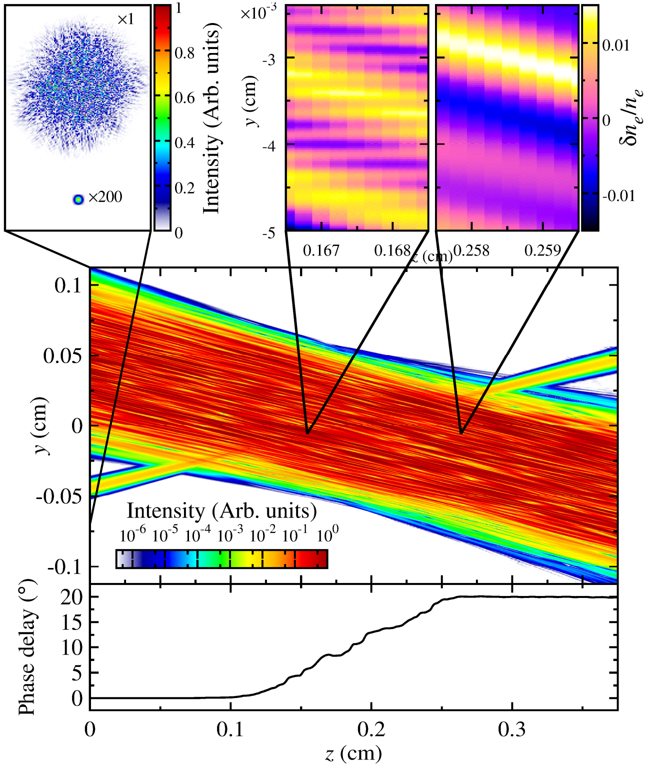

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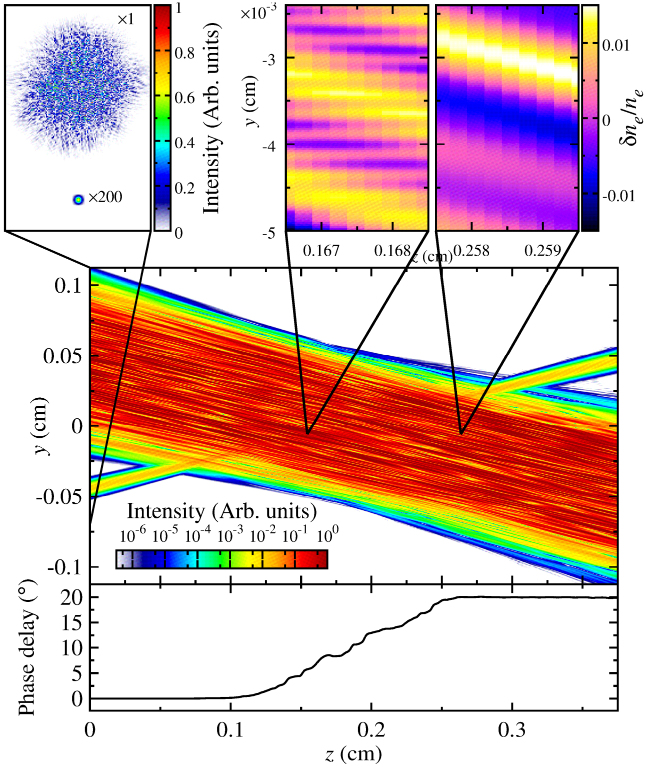

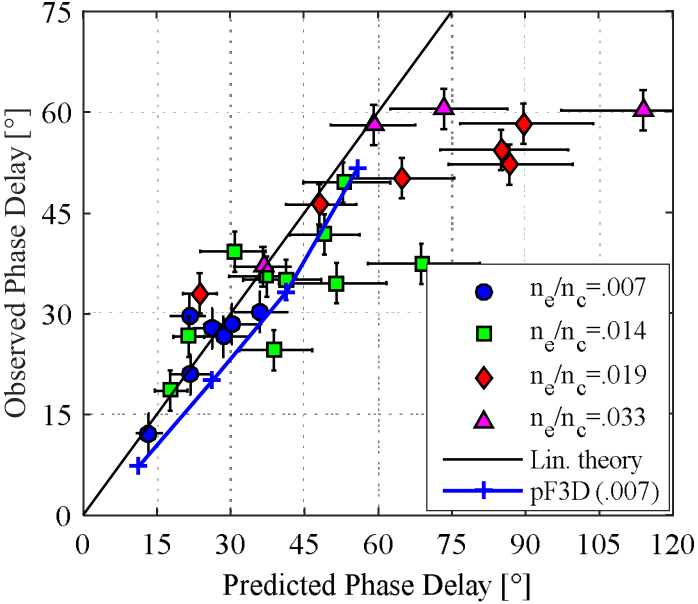

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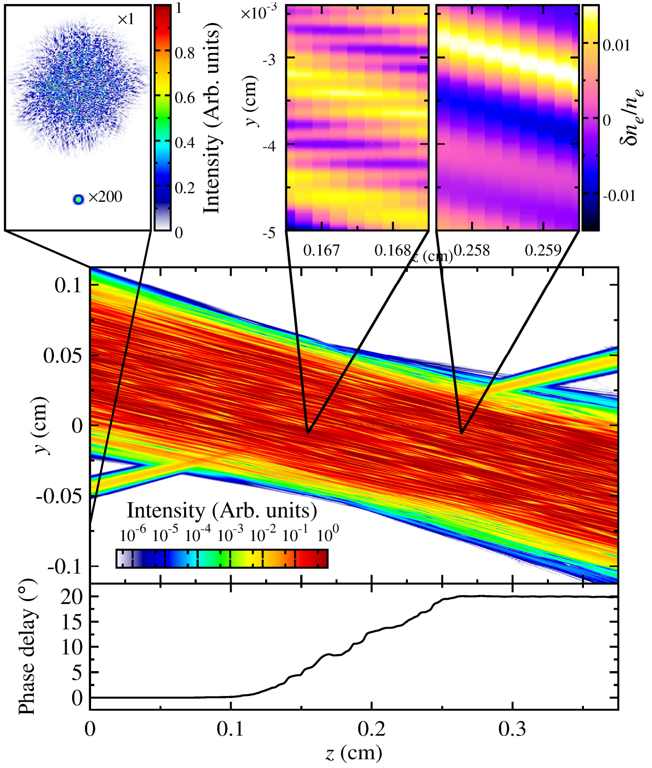

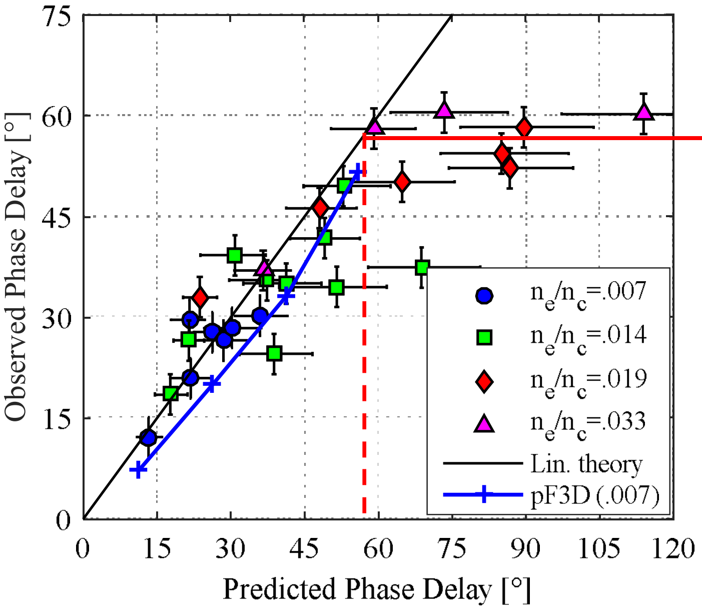

pF3D indicates significant energy transfer in strong-coupling regime of SBS when $\gamma/kc_s \approx 1$

Simulations by T. Chapman

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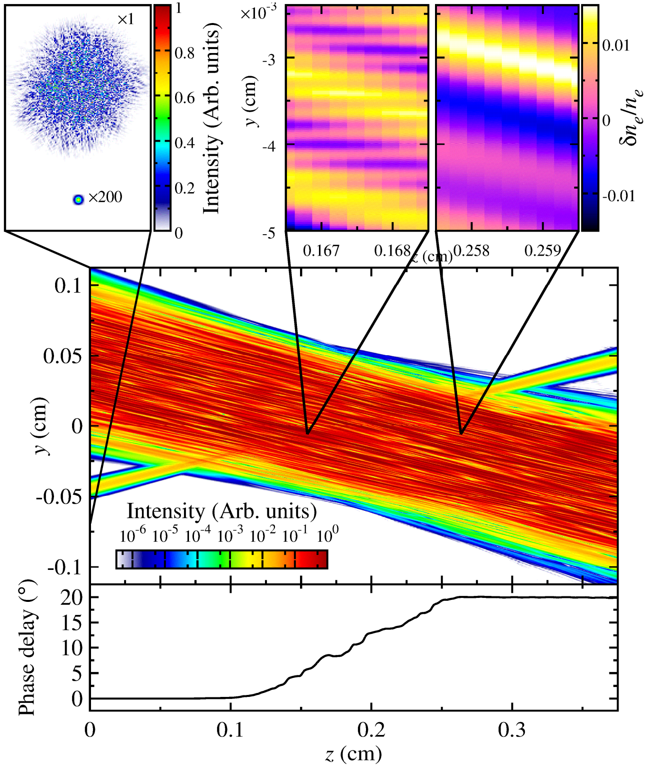

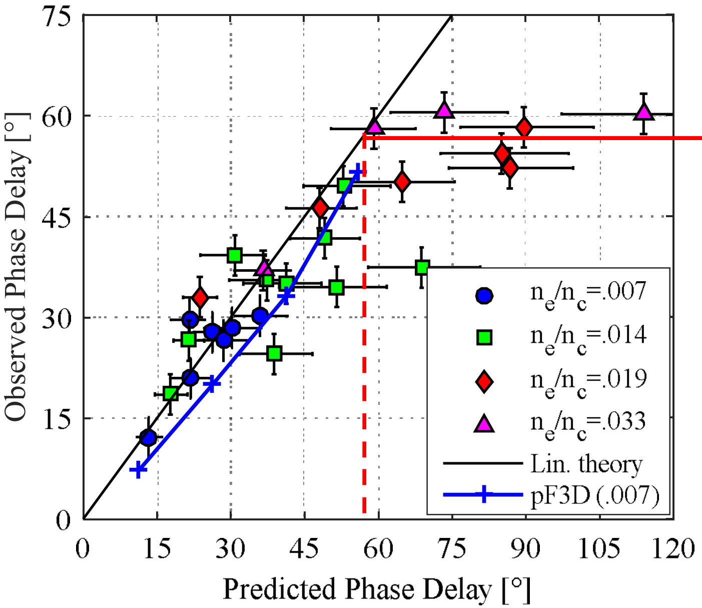

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Simulations by T. Chapman

Limits are understood, and pF3D is a predictive design tool

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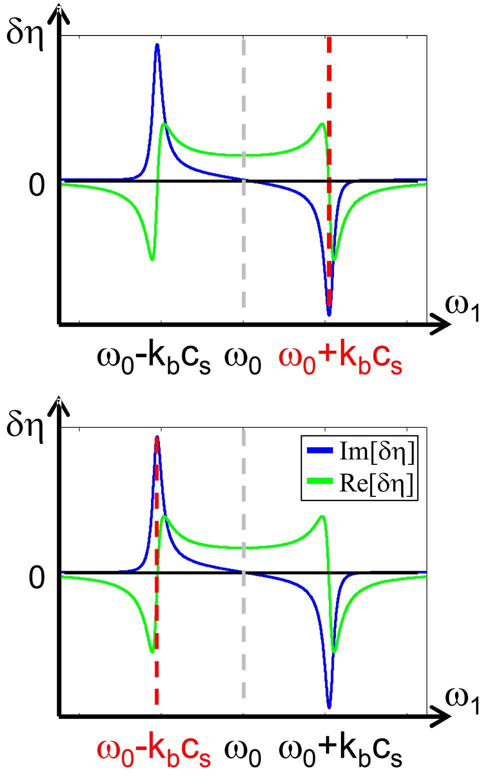
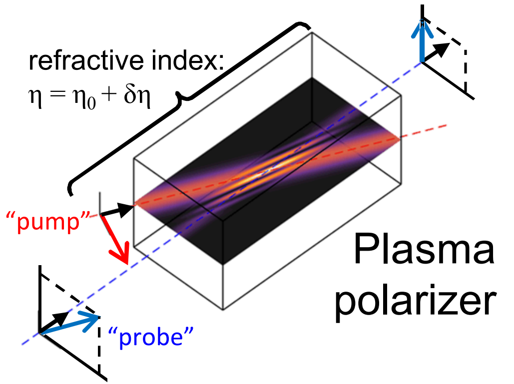
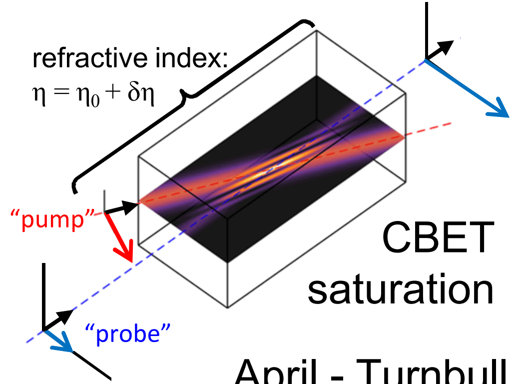
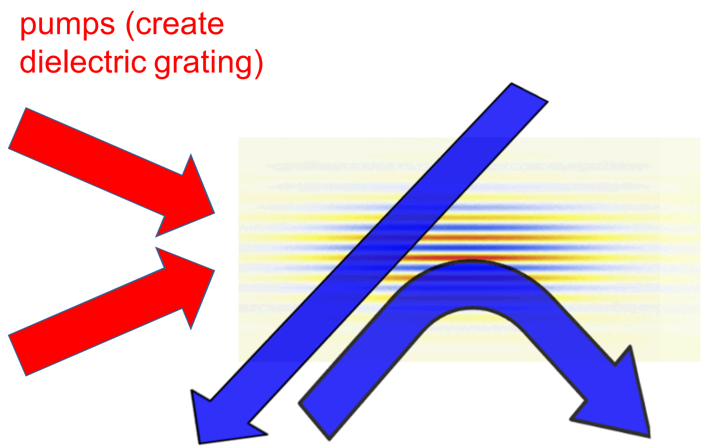
We requested wavelength tuning capability, which will enable many new and exciting experiments







April - Turnbull



Four-wave mixing

Both expts supported by P. Michel's new LDRD

May - Goyon

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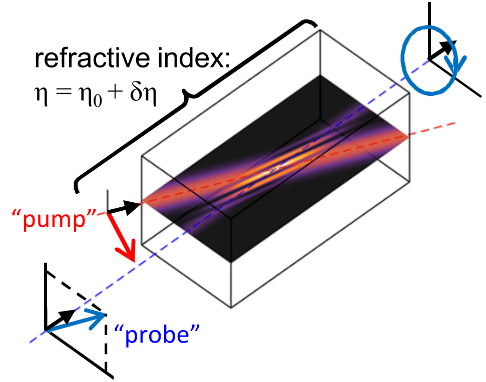

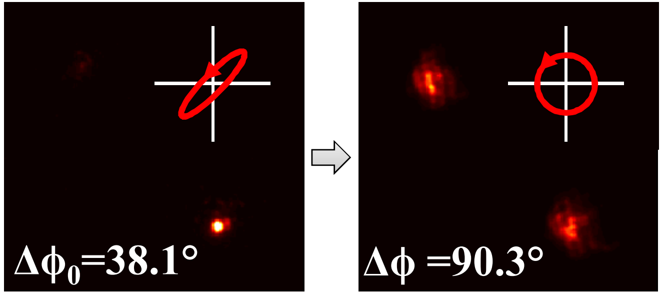

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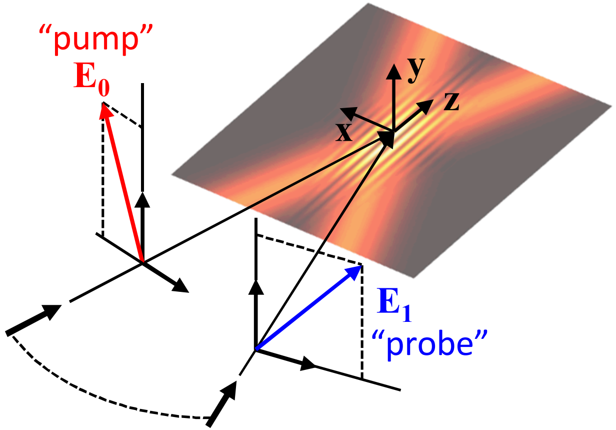
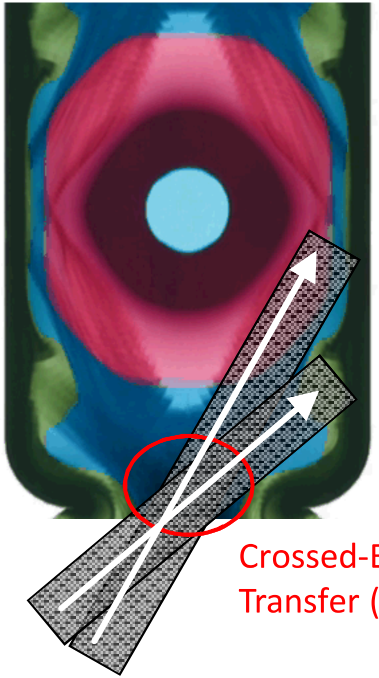
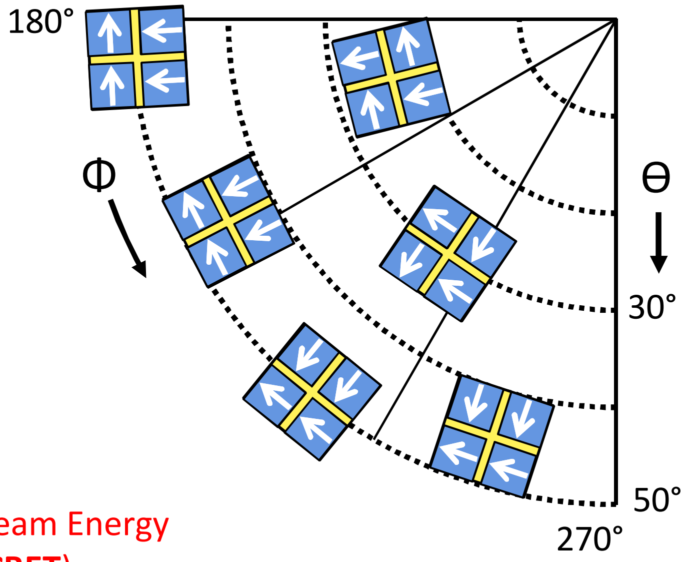
Theory developed for arbitrary polarizations is relevant to incident beam propagation in NIF hohlraums

Linear theory validated in weak-coupling regime for two beams in well-diagnosed plasma





Crossed-Beam Energy Transfer (**CBET**)



We can measure the polarization of SBS backscatter, which is imprinted with the effect of crossed beam interactions